QUANTITATIVE SAFETY ASSESSMENT OF THE TOW2 TEST SHOOTING IN SWITZERLAND

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Abstract:

The Swiss DoD Technology and Procurement Agency regularly performs experimental and qualification test shootings with TOW2 antitank missiles (manufactured under licence in Switzerland) in a valley in the Swiss Alps. The original safety concept for these shootings based on US developed "Surface Danger Zones (SDZ)" handed out with the licence. These SDZ originally covered the area in front of the firing position, but later they were extended with a large area behind and at the side after a number of "fire back" events had happened in the US and NATO. The new SDZ actually covered a pass road and the houses of a few small villages. On the other hand, they seemed, at least in the actual geographic conditions, to overshoot the mark distinctly. A quick and rough first estimation showed indeed that there would not be a significant risk for third persons. But as it is sometimes more difficult to prove an activity to be safe than to show that it is unsafe, the Technology and Procurement Agency had a comprehensive quantitative safety assessment done by Bienz, Kummer & Partner Ltd. The aim of the assessment was to prove that the individual risks of the third persons in the surroundings and those of the shooting crew as well as the collective risk were within the limits laid down in the respective Swiss regulations.

The presentation demonstrates that - even within tight financial limits - a systematic and quantitative approach for the evaluation of the hazards of such a problem is possible and useful. It is illustrated how the assessment was done and how the missing data on frequencies and hazardous effects were provided by simple models and expert judgements. Finally, the results and recommendations deduced are discussed.

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1. INTRODUCTION

Since 1989, the Swiss DoD Technology and Procurement Agency has regularly performed experimental and qualification test shootings with warhead equipped TOW2 antitank missiles (manufactured under licence in Switzerland) in a valley in the Swiss Alps. The original safety concept for these shootings was based on US developed "Surface Danger Zones (SDZ)" handed out with the licence. These SDZ originally covered the area in front of the firing position, but later they were extended with a large area behind and at the side after a number of "fire back" events had happened in the US and NATO (S 1). As we understood those missiles had been launched from the launch tube by the launch motor but the cruising motor had failed to start ("eject only") such that the missiles had crashed to the ground some 50 - 100 m in front of the launchers whereby the missiles had been whirled around and, the warhead having been activated during the launch phase, the shaped charges had gone off towards the rear, i.e. towards the launcher position.

The new SDZ applied to the Swiss testing area actually covered a pass road and the houses of a few small villages. On the other hand, they seemed, at least in the actual geographic conditions, to overshoot the mark distinctly. A rough first estimation showed indeed that there would not be a significant risk for third persons. But as it is sometimes more difficult to prove an activity to be safe than to show that it is unsafe, the Technology and Procurement Agency had a comprehensive quantitative safety assessment done by Bienz, Kummer & Partner Ltd. The aim of the assessment was to prove that the individual risks of the third persons in the surroundings and those of the shooting crew as well as the collective risk were within the limits laid down in the respective Swiss regulations.

2. DESCRIPTION OF US SURFACE DANGER ZONES

The Swiss Technology and Procurement Agency was informed about the Surface Danger Zones (SDZ) in September 1987. After eight years it was impossible to get in contact with the authors. It was therefore impossible to clarify some obvious contradictions and to know more about the probability models used.

The heart of the SDZ are the marked areas on this slide (S 2). According to the report, 999'999 out of 1 mill. missiles should land within the impact area in front of the launcher with an angle of 94°. 5.5% of the fired missiles should land in area I with a radius of 800 m. This so-called Primary Danger Area is expanded with area B which has the size of 750 or 100 m, according to the fragmentation-area of missiles with war head or inert head.

Area H, a circular sector to the rear of the launch position, was established as an additional buffer zone "to protect personnel from the hazards of high velocity fragments and missile debris resulting from detonation of the high explosive warhead during an 'eject only' event". The outer zone has a maximum radius of 3200 m and the inner concentric arc a radius of 1300 m. It is mentioned that the slug of the shaped charges would fly up to 3200 m and 100 fragments produced by such an event up to around 1300 m.

Area H is divided into 4 sectors. The slug and 100 fragments of the 59 "eject only" out of 1 mill. events would land in the two areas behind the launcher position, those of 20 "eject only" would fly to the two areas beside the launcher position.

After a thorough analysis, taking into account the realistic possibilities, some contradictions became obvious and a number of questions arose. For instance in area B the range of fragments as well as slug is indicated with 750 m. In area H however they fly up to 1300 or 3200 m respectively.

If the slug really can fly 3200 m is an other question. The initial velocity of the slug is around 300 m/s but the projectile has no spin and its form is ballistically not advantageous.

The "100 fragments" mentioned in the reports must be the numerous spindle-shaped metal drops (Swiss experts say 10 - 20 drops weighing 20 - 50 g each) produced by the shaped charge. The fragments from the head cover of the shaped charge are expected to fly about 100 m which is much less than 1300 m.

The range of a missile accelerated only by the launching motor is estimated to be around 100 m and seems not to matter a lot compared with the 1300 resp. 3200 m because the shooting position is taken as central point of the circle.

The given probabilities could not be scrutinized as their basis was not available.

3. EXPERIENCES WITH TEST SHOOTING IN SWITZERLAND

The complete rate of miss-the-marks is not mentioned in the SDZ. In general, when shooting missiles like the TOW2 a crash rate of around 10% is observed. Hence, as a basis for our analysis we studied the crash rate and impact allocation of the test-shootings performed by the Technology and Procurement Agency in Switzerland since 1989 (S 3).

The total rate of nearly 17% seems to be relatively high compared to the around 10% expected. But it could be explained with some technical errors that were discovered and figured out during these shootings and improved in the meantime.

In 95% of the crashes the war head exploded and in all cases no "fire back" event occurred. One "eject only" happened (crash at ca. 100 m) because the cruising motor was not ignited due to an electrical problem. In this case the shaped charge of the war head was not activated however.

The crash rate of 5.6% within the first 800 m correspond very well with the 5.5% given by the SDZ, but this seems to be a mere coincidence. No crash location was more than around 100 m away from the shooting axis.

4. PROCEDURE OF THE RISK ANALYSIS

The practical procedure followed the common steps of a risk analysis and safety assessment:

- In the event analysis the probability, location and type of the possible hazardous event were investigated and described in the respective terms.

- In the effect analysis the effects of the hazardous events were calculated in terms of lethality zones.

- In the exposure analysis the possibly exposed persons were identified .

- In the risk calculation the individual risks of the exposed and the collective risk of the test shooting activity were determined.

- In the risk appraisal the calculated risks were appraised versus the safety criteria laid down for the DoD.

Concerning the details of the risk analysis procedure I refer to some papers presented at former Explosives Safety Seminars [Lit. 1 - 6] which treated the risk approach, methodology, criteria etc. and also case studies. Following some comments on the practical procedure:

The first is one I often have to express: There were a lot of missing data and open questions. On the other hand the financial means were definitely limited. This meant that we could not go into all interesting details to fulfil scientific expectations but had to stop when the lack of knowledge could be supplied by simplifying models and expert judgement without a bad conscience.

We did not restrict ourselves to the simple "fire back" phenomena. After having seen a video tape (recorded in the US) showing a TOW missile whirling around just after the launch like a supersonic mosquito we also investigated the case "touch and stagger", i.e. a missile rising after a crash driven by the cruising motor. Actually, there were no data and statistical experiences. The maximum range for such a damaged missile was assumed to be 300 m in all directions from the launcher. The frequency was deduced from the assumption, 1 of 1000 would be a "touch and stagger", out of which 1 of 300 would be followed by an explosion of the warhead with slug and drops flying in the surroundings (and not into the ground).

The probability of a crash and the local distribution was deduced from the statistical base of the Swiss test shootings because there were no other sources available. This slide (S 4) shows the distribution of the probability of a crash per missile fired. The local distribution of the probability of slug and drops effects occurring in the surroundings was taken from the SDZ.

In the effect analysis we distinguished between the hazardous effects in all directions dominated by the airblast and normal fragments from the warhead with a maximum range of about 100 m and the conically focused effects of the shaped charge, i.e. mainly drops and slug. For the calculation of the lethalities of the shaped charge effects we had to help ourselves with simplified models. For instance we assumed that all drops and the slug would disperse within a sector of 30° and fly up to 1300 m and the slug 3200 m, having a lethal energy in case of a hit at the sensitive area of a human being (assumed to be 0.2 m^{2}). (S5) For the fragment distribution we applied a cylinder segment model for the nearfield and a spherical segment model for the farfield area.

The result of the effect analysis combined with the probabilities were lethality zones like e.g. this one (S 6). It shows the lethality distribution per missile for people exposed in the open caused by the all-

direction effects in the "fire back" case, and this one (S 7) that of the slug and drops for ranges longer than 500 m. In both slides the topography is not taken into account. (This is accurate enough as most of the exposed people live or walk or drive in the valley bottom and not in the scree slopes of the surrounding mountains).

In the exposure analysis 14 objects were identified and described with respect to location and number of persons exposed, time history and type of protection (i.e. the open, house or car). With this information and the lethality zones the individual risks of the exposed persons and the collective risk of the whole activity considering the test shooting program of a year could be calculated. Slide (S 8) gives an impression of the calculation of the collective risk.

It has to be added that sensitivity checks were also performed. Generally, all the models and data were supposed to be on the conservative side. Thus, the real risks were not assumed to be underestimated by factors. Even if the true risks were two to three times the calculated risks the conclusions would have been the same.

5. DISCUSSION AND APPRAISAL OF THE RISKS

The total collective risk[1)] was calculated as about $4 \cdot 10^{-4}$ fatalities/year (S 9). Actually, this is a rather small risk being about 1000 times lower than e.g. the risk caused by the transport of dangerous goods by the Swiss railway or 2 mill. times lower than the road traffic risk in Switzerland. I have to point out that such risk comparisons are very delicate, but here it can be stated with a good conscience that the TOW2 test shooting is not a safety problem of prime importance in Switzerland.

Most of the risk is caused by "fire back" events; the risk caused by "touch and stagger" events amount only to a few per cent of the total risk. About half of the risk is borne by persons in the nearfield (i.e. mainly the shooting crew), about a third by drivers and passengers on the pass road, about a sixth by people in the open and only a few per cent by people living in the neighbouring hamlets and villages.

[1)] Actually the **risk-group-adjusted perceived collective risk** was calculated. The Swiss Safety Concept considers that the acceptance of risks depends on the relationship of the exposed person to the hazardous activity and to what extend the person is able to influence this risk. The safety criteria are based on a simplified model which distinguished four categories of risk. Two of them are relevant in the field of safety of explosives and ammunition: (1) The risk of third persons in the surroundings of a storage or a factory belongs to the involuntary and not influenceable risks. (2) The risks of people earning their money by working with dangerous goods with a low ability to influence and a low degree of self-determination, but a certain perceived benefit. Because it is possible to enter only 1 tangent of marginal cost in a risk/cost-diagram, the collective risks of the different risk groups have to be adjusted against one group according to the relationship of their marginal cost to these of the group chosen for the diagram .

The perceived collective risk is the real collective risk increased by an aversion function which takes mainly into account that the reaction of the public is much more violent to rare events with large consequences than to more frequent events with less consequences per accident.

The highest individual risks (S 10) (10^{-4} fatality/year) are borne by members of the shooting crew and by the shepherd of the cattle (about 10^{-5} fatality/year) put out to pasture near the shooting area. The maximum risks among other third persons are small ($3 \cdot 10^{-6}$ fatality/year) and are in the range of common everyday risks.

How do the calculated risks compare with the safety criteria? The highest individual risks are not negligible but they are within the safety criteria of

10^{-4} fat./year for direct involved persons (i.e. shooting crew) and
10^{-5} fat./year for not involved third persons.

Thus, from the point of view of the individual risks the TOW2 test shooting is considered safe.

For the appraisal of the collective risk there are no upper limiting values. The collective risk has to be appraised applying a marginal cost criterion (we presented the method and its reasons at former Explosives Safety Seminars). The criterion is 20 million CHF (= about 17 million US$) per saved victim among third persons. (S 11) In this particular case the discussion runs as following:

- For reducing the whole calculated collective risk up to the maximum of about 8'000 CHF (= about 6700 US$) could/should be spent if there are adequate precautions. Otherwise, the risk can be accepted.

- But there are indeed possible measures which, in this particular case, do not cost anything but personal discipline and for the superiors ability to assert themselves:

  (1) At the moment the missile is fired, all of the shooting crew and the shepherd have to be in the nearby house specially designed and built for this purpose (a member of the crew has made a habit out of looking at the flying missiles from the roof of the building, from time to time together with the shepherd; a "fire back" or a "touch and stagger" would endanger them strongly).

  (2) The rest of the crew working around the magazine building nearby have to be in the magazine at the moment the missile is fired.

  The collective risk can be reduced by about 30%. In the same time, the individual risk of the crew member on the roof will be reduced remarkably.

- The remaining collective risk of about $2.8 \cdot 10^{-4}$ fat./year is accepted as there are no measures left reducing this risk within this cost limit.

6. FINAL REMARKS

The systematic quantitative risk approach has again proved its usefulness like in numerous other cases before. Within reasonable financial limits it could be shown that according to the safety criteria laid

down for the Swiss DoD the TOW2 test shooting performed by the Technology and Procurement Agency is safe provided the shooting crew makes maximum use of the existing protective structures.

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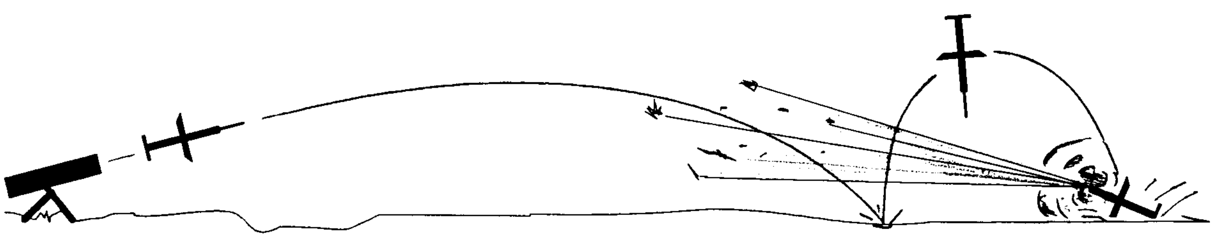
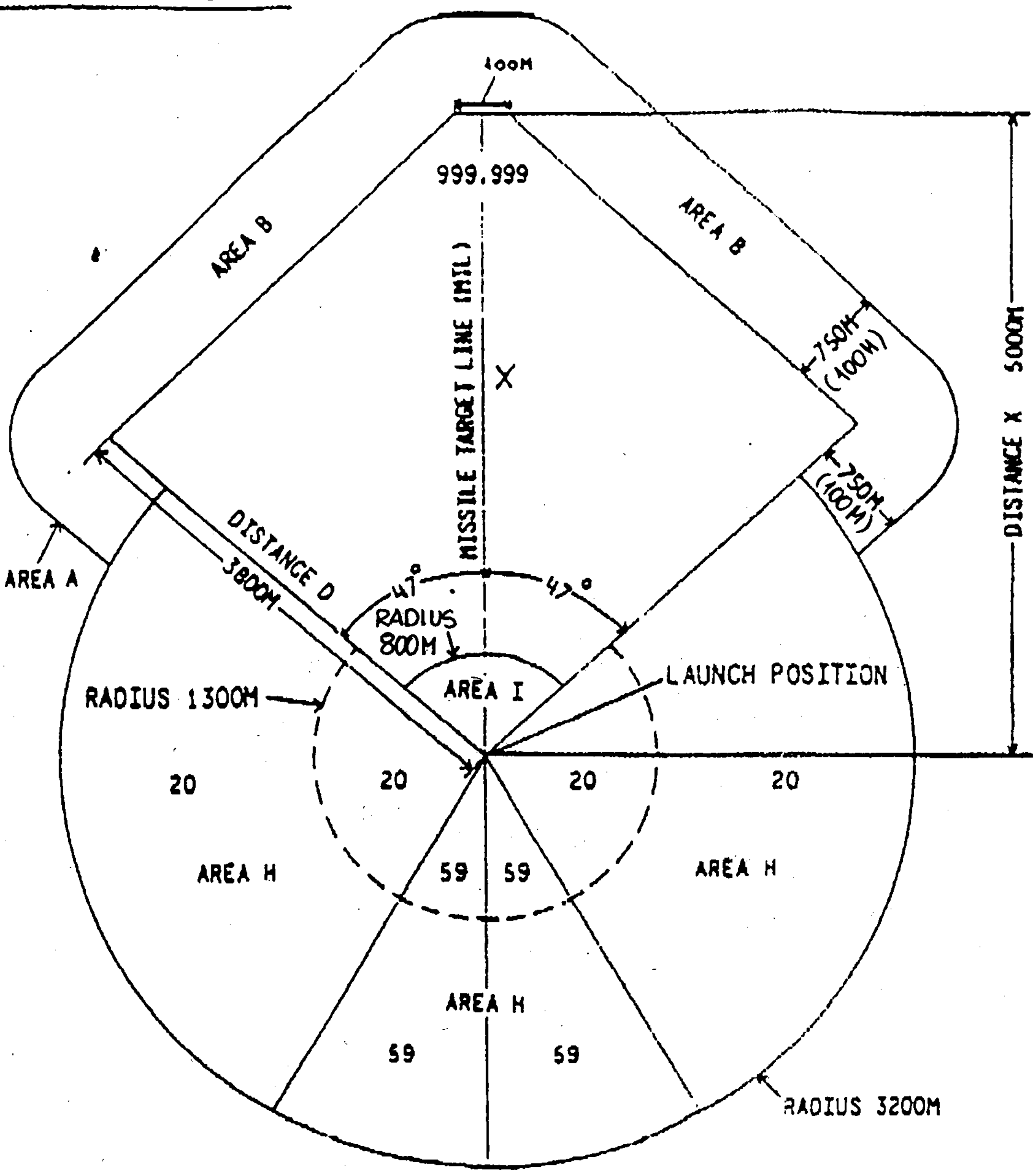
"Fire Back" Event S 1



Surface Danger Zone S 2

47 DEGREE SDZ



The expected number of "Eject Only" warhead events detonating, and firing back with warhead fragments and slug into Area H per 1,000,000 firings (probability estimate only).

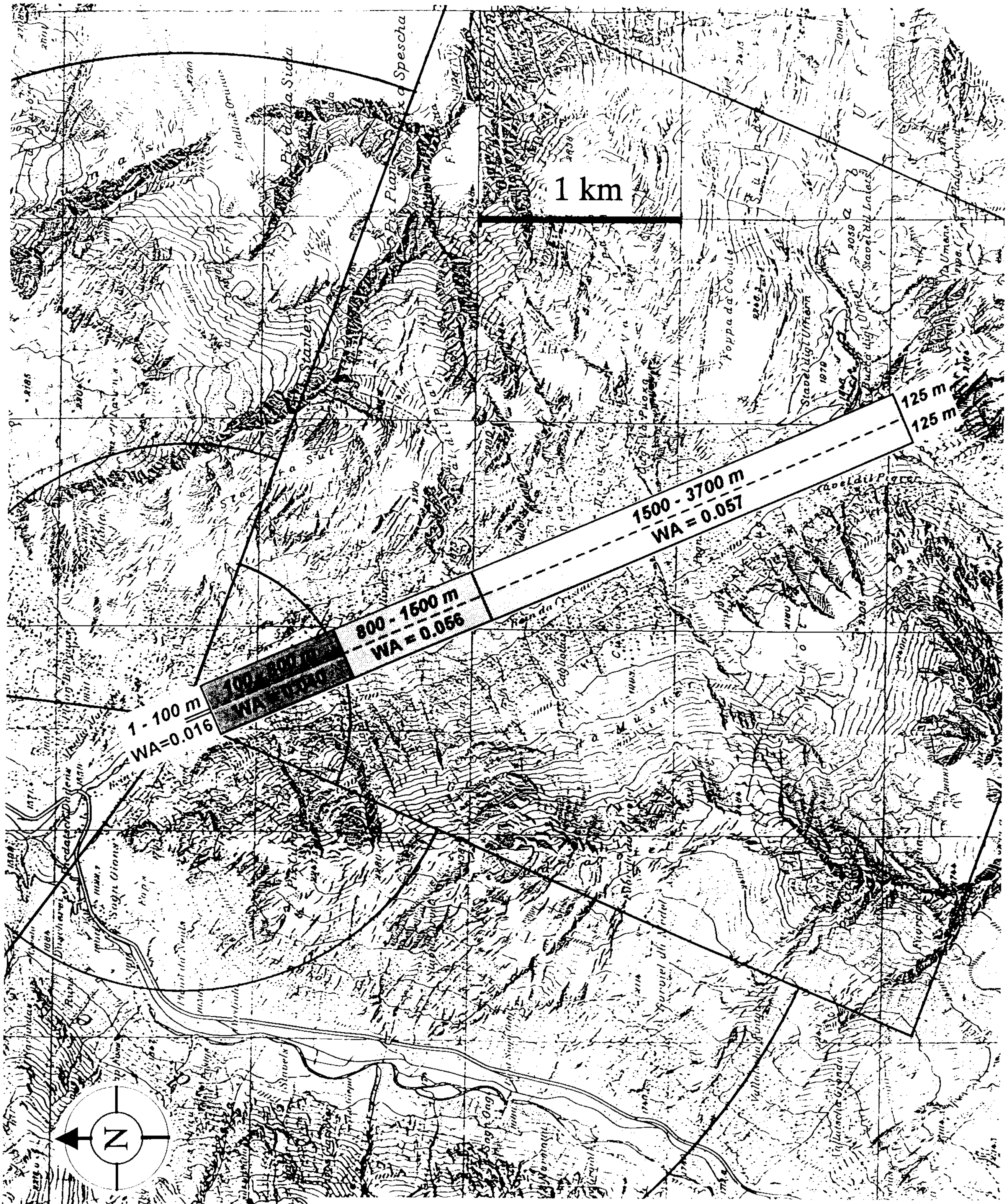
NOTE: In each event, approximately 100 fragments are expected to impact within the 1300 meter circular sector (shown as a dotted line), and 1 slug is expected to impact within the 3200 meter circular sector.

NOT TO SCALE

Actual Swiss Failure Rates S 3

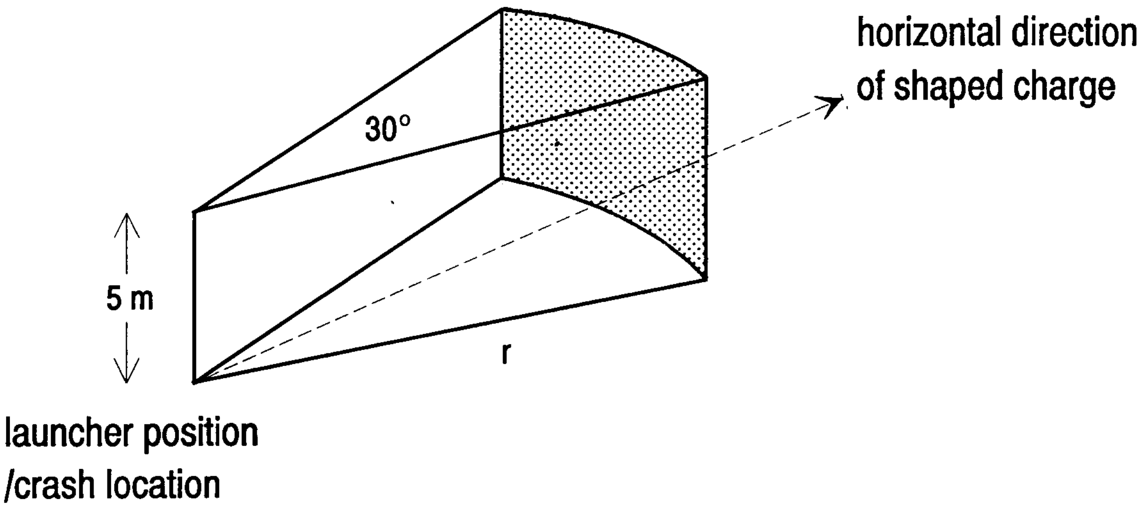
Total Missiles Fired 1989-1994		100%
Total Crashes		16.8%
Range	0 - 100 m	1.6%
Range	100 - 800 m	4.0%
Range	800 - 1500 m	5.6%
Range	1500 - 3700 m	5.6%

Crash Probability Distribution S 4

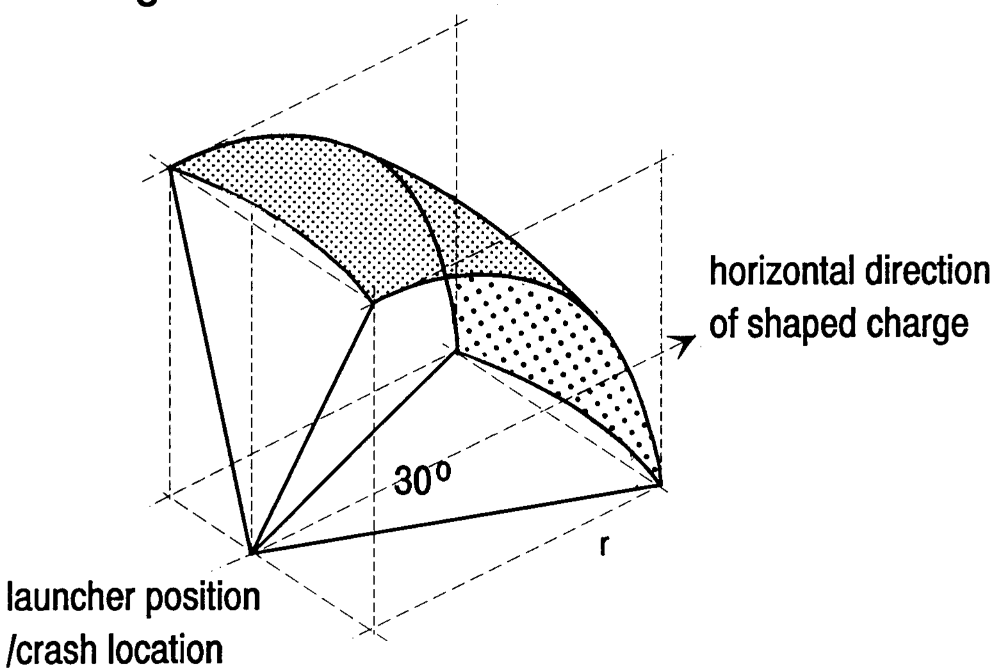


Fragment Distribution Models S 5

Cylinder Segment Model

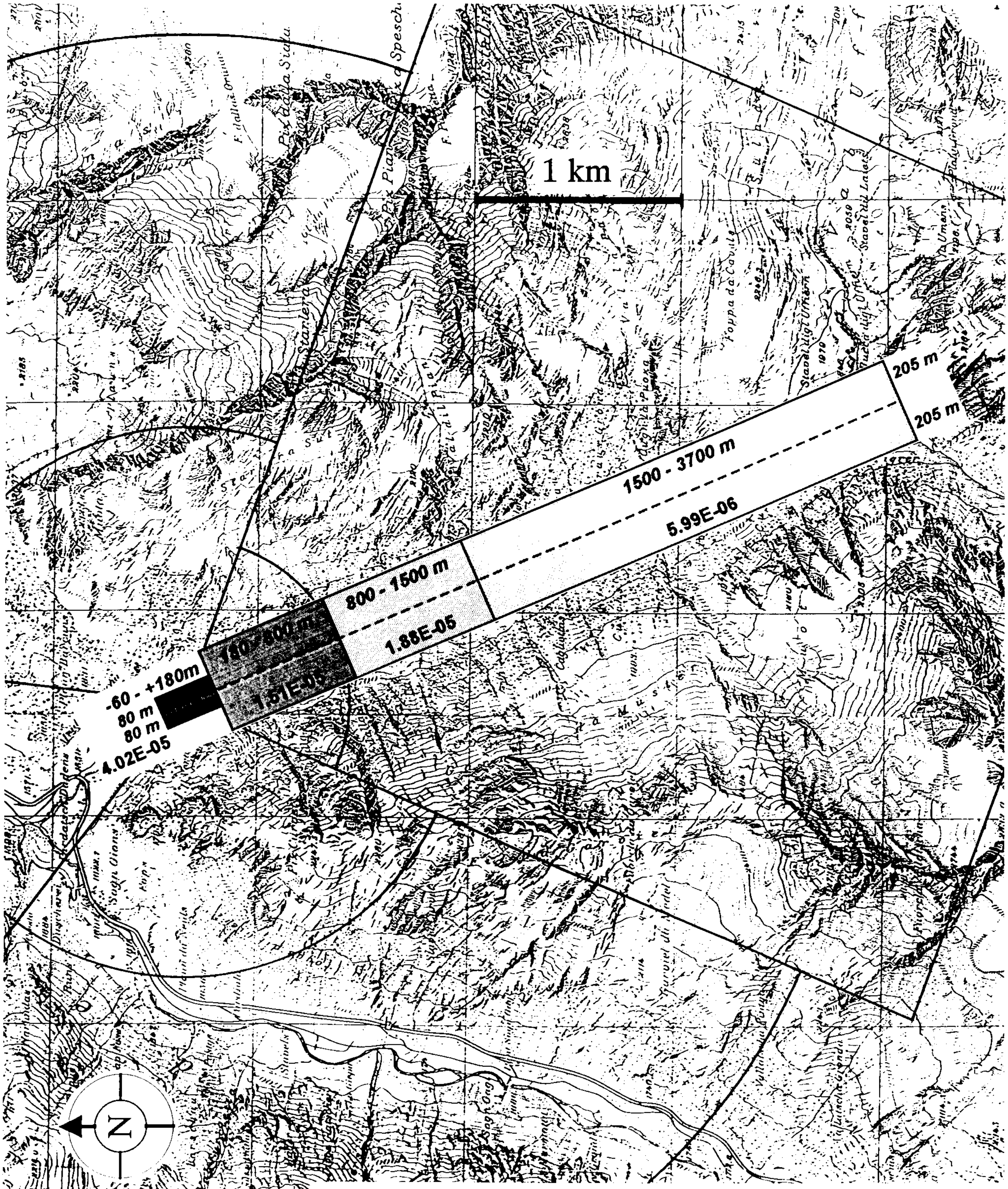


Spherical Segment Model



Lethality Zone — S 6

"Fire Back"/Spherical Effects - Lethality per Shot



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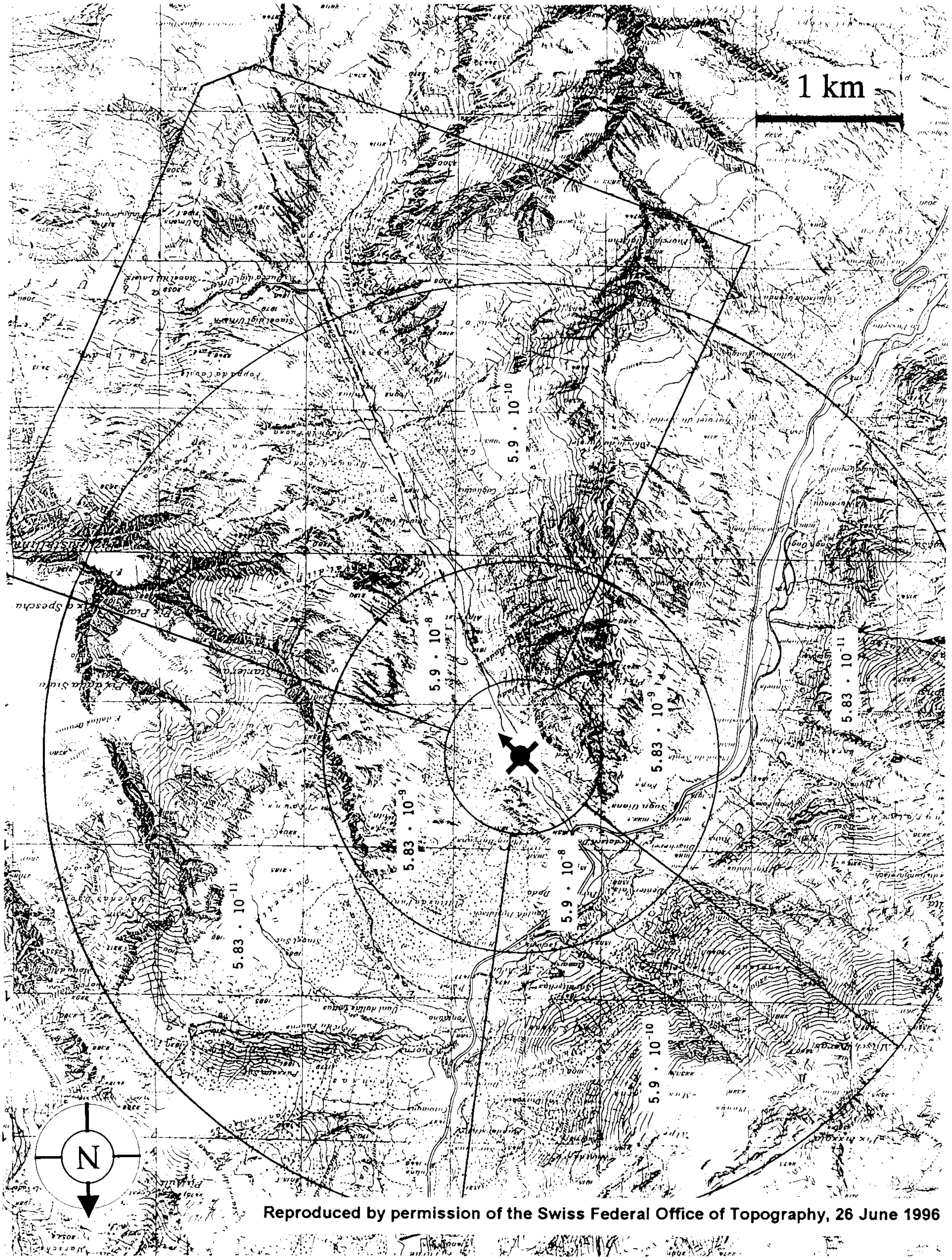
Lethality Zone S 7

"Fire Back"/Slug and Drops - Lethality per Shot



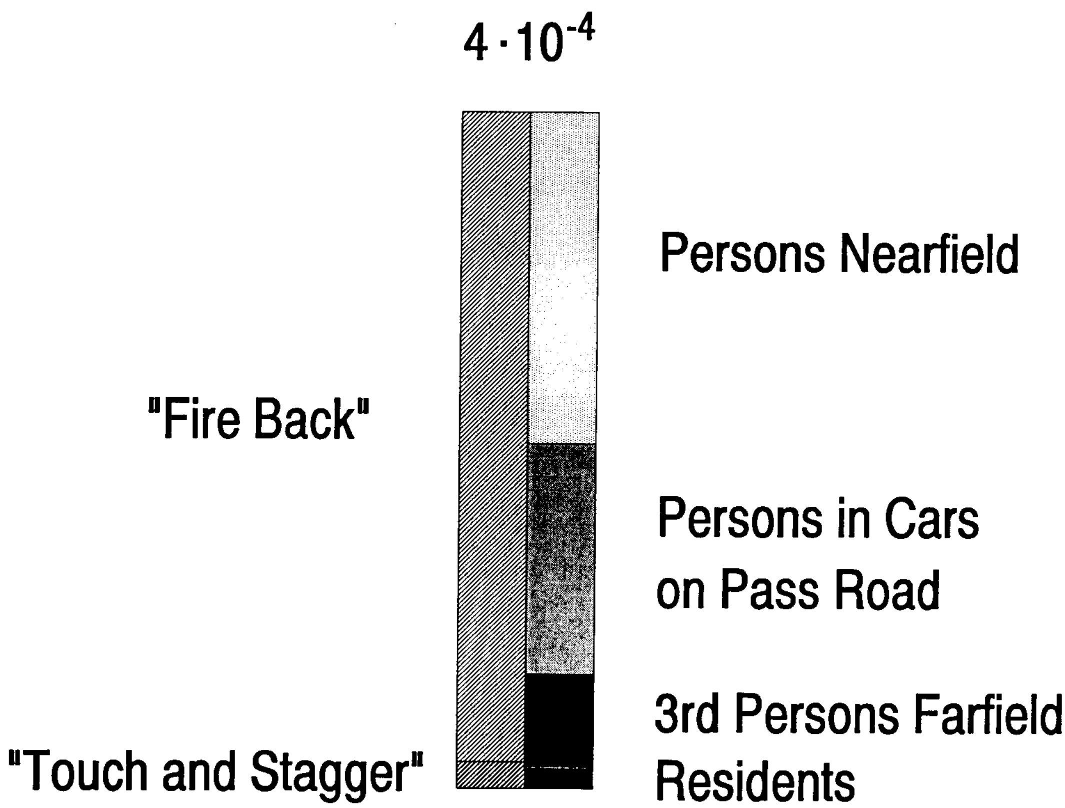
Calculation of Collective Risk — S 8

	OBJEKT	Prä-senz	R.-Gr.	Risikoanteile der versch. Wirkungen (inkl. Präsenz)					Sch.-fakt.	KOLLEKTIVE RISIKEN		
				FB/AW	FB/S+D<	FB/S+D>	T+S/AW	T+S/S+D		pro Sch.	pro Jahr	ber. UD
1	**Abschussgeb.**											
	2 P. im Haus	100%	DB	8.04E-05	1.18E-06	-	4.26E-07	1.20E-08	100	8.20E-07	4.10E-05	8.20E-06
	1 P. auf Haus	5%	DB	2.01E-06	2.95E-08	-	1.07E-08	3.00E-10	1	2.05E-06	1.03E-04	2.05E-05
	1 P. auf Haus	0.5%	UD	2.01E-07	2.95E-09	-	1.07E-09	3.00E-11	1	2.05E-07	1.03E-05	1.03E-05
2	**Auswertgeb.**											
	4 P. im Haus	100%	IB	-	2.36E-06	-	8.52E-07	2.40E-08	10	3.24E-07	1.62E-05	6.47E-06
	3 P. im Haus	20%	UD	-	3.54E-07	-	1.28E-07	3.60E-09	10	4.85E-08	2.43E-06	2.43E-06
3	**Werkstatt/ Mag.**											
	4 P. im Freien	100%	IB	-	2.36E-06	-	8.52E-07	2.40E-08	1	3.24E-06	1.62E-04	6.47E-05
4	**Schiessw. Talein.**											
	1 P. im Freien	100%	IB	-	5.90E-07	-	2.13E-07	6.00E-09	1	8.09E-07	4.05E-05	1.62E-05
5	**Pardatsch Dadens**											
	5 P. in Häusern	100%	UD	-	-	2.95E-07	-	1.25E-08	10	3.08E-08	1.54E-06	1.54E-06
	5 P. im Freien	100%	UD	-	-	2.95E-07	-	1.25E-08	1	3.08E-07	1.54E-05	1.54E-05
6	**Sogn Glons**											
	8 P. in Häusern	100%	UD	-	-	4.66E-08	-	2.00E-09	10	4.86E-09	2.43E-07	2.43E-07
	8 P. im Freien	100%	UD	-	-	4.66E-08	-	2.00E-09	1	4.86E-08	2.43E-06	2.43E-06
7	**Duscherei**											
	4 P. in Häusern	100%	UD	-	-	2.33E-08	-	1.00E-09	10	2.43E-09	1.22E-07	1.22E-07
	2 P. im Freien	100%	UD	-	-	1.17E-08	-	5.00E-10	1	1.22E-08	6.08E-07	6.08E-07
8	**Denter Vals**											
	2 P. in Häusern	100%	UD	-	-	1.18E-07	-	5.00E-10	10	1.19E-08	5.93E-07	5.93E-07
	1 P. im Freien	100%	UD	-	-	5.90E-08	-	2.50E-10	1	5.93E-08	2.96E-06	2.96E-06
9	**Surtatschas**											
	3 P. in Häusern	100%	UD	-	-	1.77E-09	-	7.50E-12	10	1.78E-10	8.89E-09	8.89E-09
	3 P. im Freien	100%	UD	-	-	1.77E-09	-	7.50E-12	1	1.78E-09	8.89E-08	8.89E-08
10	**Acla**											
	3 P. in Häusern	100%	UD	-	-	1.77E-09	-	7.50E-10	10	2.52E-10	1.26E-08	1.26E-08
	3 P. im Freien	100%	UD	-	-	1.77E-09	-	7.50E-10	1	2.52E-09	1.26E-07	1.26E-07
11	**Fuorns**											
	10 P. in Häusern	100%	UD	-	-	5.83E-10	-	2.50E-11	10	6.08E-11	3.04E-09	3.04E-09
	10 P. im Freien	100%	UD	-	-	5.83E-10	-	2.50E-11	1	6.08E-10	3.04E-08	3.04E-08
12	**Parde**											
	10 P. in Häusern	100%	UD	-	-	-	-	2.50E-11	10	2.50E-12	1.25E-10	1.25E-10
	10 P. im Freien	100%	UD	-	-	-	-	2.50E-11	1	2.50E-11	1.25E-09	1.25E-09
13	**Freifeld (6 P./km²)**											
a)	4 P. im Freien	100%	UD	-	-	2.36E-07	-	1.00E-08	1	2.46E-07	1.23E-05	1.23E-05
b)	4 P. im Freien	100%	UD	-	-	2.36E-07	-	1.00E-09	1	2.37E-07	1.19E-05	1.19E-05
c)	4 P. im Freien	100%	UD	-	-	2.33E-08	-	1.00E-09	1	2.43E-08	1.22E-06	1.22E-06
14	**Strasse**											
a)	18 P. in Autos	100%	UD	-	-	1.05E-09	-	4.50E-11	1	1.09E-09	5.47E-08	5.47E-08
b)	18 P. in Autos	100%	UD	-	-	5.31E-07	-	2.27E-09	1	5.33E-07	2.67E-05	2.67E-05
c)	18 P. in Autos	100%	UD	-	-	1.06E-06	-	2.48E-08	1	1.09E-06	5.43E-05	5.43E-05
d)	18 P. in Autos	100%	UD	-	-	1.05E-07	-	4.50E-09	1	1.09E-07	5.47E-06	5.47E-06
Geamtes tatsächliches kollektives Risiko /Jahr												**2.65E-04**
Gesamtes empfundenes kollektives Risiko /Jahr						Annahme: Ausmass=3 Opfer ->			$\varphi =$	1.516		**4.01E-04**

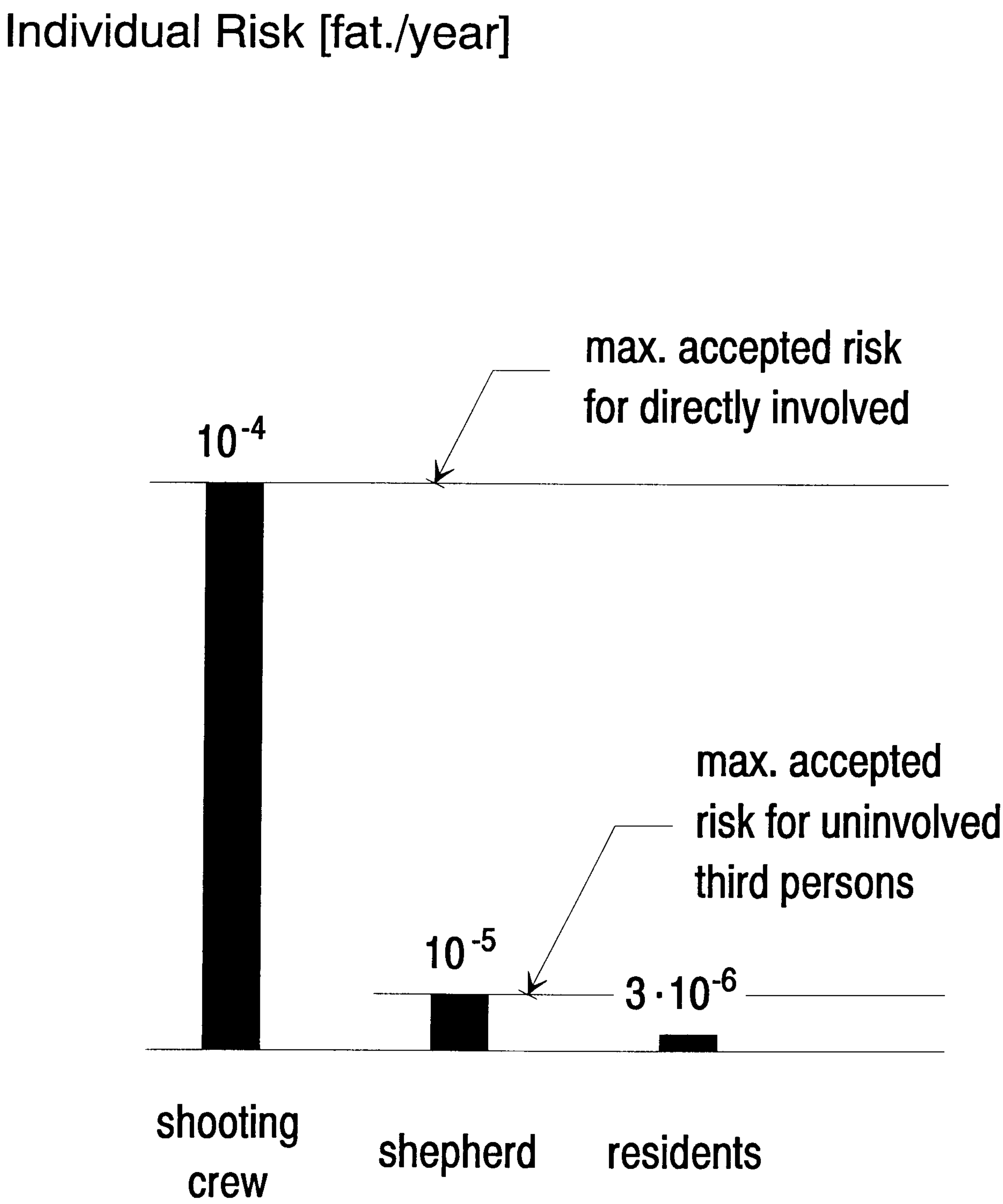
Calculated Collective Risk S 9

Total Perceived Collective Risk [fat./year]

(risk group adjusted (3rd person))



Calculated Individual Risks S 10



Appraisal of Collective Risk S 11